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Nonpoint source pollution uncertainty: Stakeholder perceptions

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***Abstract*.** High variability of nonpoint source (NPS) pollutant loads caused primarily by uncontrollable precipitation events creates great uncertainty for those charged with NPS management. Stakeholder disagreement on the best way to address the uncertainty issue can lead to inaction. However, understanding different stakeholder perspectives could promote consensus and a unified effort to effectively address this difficult pollution problem. This paper probes methodologies for quantifying the uncertainty of soil erosion and sediment load predictions and evaluates stakeholder perceptions of the issue through a focus group study. Three groups, each consisting of 5 to 8 individuals, convened to answer a set of questions designed to promote discussion of soil erosion and sediment load prediction uncertainty. One group was composed of natural resource professionals and scientists, another of individuals with environmental interests, and the third of producers and producer association representatives. The goal of the study is to gain insight into perceptions of NPS pollution uncertainty, the need for its quantification, and its impact on water quality improvement efforts. The findings of this study have important implications for EPA's TMDL program and other NPS pollution control initiatives.

Keywords. Focus Groups, Monte Carlo simulation, Sediment, TMDL, Uncertainty analysis

Introduction

Water quality of many U.S. streams and lakes has improved greatly since the 1970's as a result of the implementation of the CWA (Andreen 2004). The TMDL program has been effective for point sources through the implementation of NPDES permit regulations. However, nonpoint sources (NPS) contribute the greatest amounts of phosphorus, nitrate, pathogens and sediment to our waterbodies. The TMDL program has been less effective in agricultural regions because of the complex nature of NPS pollution and the unpredictability of important climatic factors. The CWA does not provide for directly regulating NPS pollution. As a result, NPS pollution has become the primary obstacle to improving water quality (Andreen 2004).

Sediment is one very important water quality parameter because deposition limits stream flow capacity, reduces water storage in lakes and reservoirs, and adversely affects aquatic ecosystems. Equally important, suspended sediment is a transport mechanism for many nutrients, pesticides and pathogens.

Improved uncertainty analysis and statistical techniques for TMDLs has been identified as an immediate TMDL development and implementation science need by the National Research Council's The Twenty Needs Report: How Research Can Improve the TMDL Program (USEPA 2002). While better uncertainty analysis and statistical techniques have been proposed for NPS pollutants, the impact of these technical advances on water quality is not clear. The TMDL program and the science which supports it has been at a loss of how to deal with the most important source of NPS load uncertainty, the weather. Also The Twenty Needs Report is "limited to analysis and recommendations concerning scientific issues". The report focuses on the physical natural resources sciences affecting water resources to the exclusion of the social sciences.

Two methodologies for predicting soil erosion and sediment load delivery are compared in this paper. The first approach demonstrates the use of the Water Erosion Prediction Project (WEPP), Version v2006.5, computer simulation model (Flanagan et al. 2007) with stochastically generated climate data from CLIGEN Version 5.2 (Nicks et al. 1995). The second approach demonstrates the traditional deterministic approach using a modification of the Universal Soil Loss Equation called MUSLE (Williams 1975) to estimate sediment delivery caused by a single precipitation event

Natural systems are very complex, but social system dynamics and the placed-based variation in civic structure are also difficult to understand, predict and influence. McCown (2005) argues that "interventions to change land management practices must address the decision–makers subjective beliefs". Incorporating knowledge from the social sciences can guide conservation policies that encourage responsible behavior through incentives that promote more effective conservation. Understanding the uncertainties of NPS pollution prediction may encourage more cooperation with, and support for, control programs. This hypothesis is tested using focus group interviews of different stakeholder types. The focus group approach provides a means for gaining insight into the collective views of the participants regarding a specific issue (Krueger and Casey 2009). The objective of this study is to compare a novel stochastic method to a deterministic method for predicting soil erosion and sediment delivery and explore stakeholder perceptions regarding uncertainty through focus group interviews.

Methods

We selected a 296 ha agricultural watershed (Figure 1) in Tama County, Iowa, as the example for this study. This 296 ha area is a sub-basin of the Four Mile Creek watershed which was the subject of years of soil erosion and sediment transport monitoring by Iowa State University scientists from 1975 to 1979. The example 296 sub-basin is small compared to typical TMDL watersheds, speeding computations for demonstration of methodology. For comparison of the stochastic approach and the deterministic approach to sediment delivery prediction two universally applied management scenarios are modeled. The two management scenarios evaluated for demonstration are corn-soybean rotations under no-till and corn-soybean rotations under a conventional spring chisel system and we compare our WEPP stochastic approach to the deterministic MUSLE methodology.

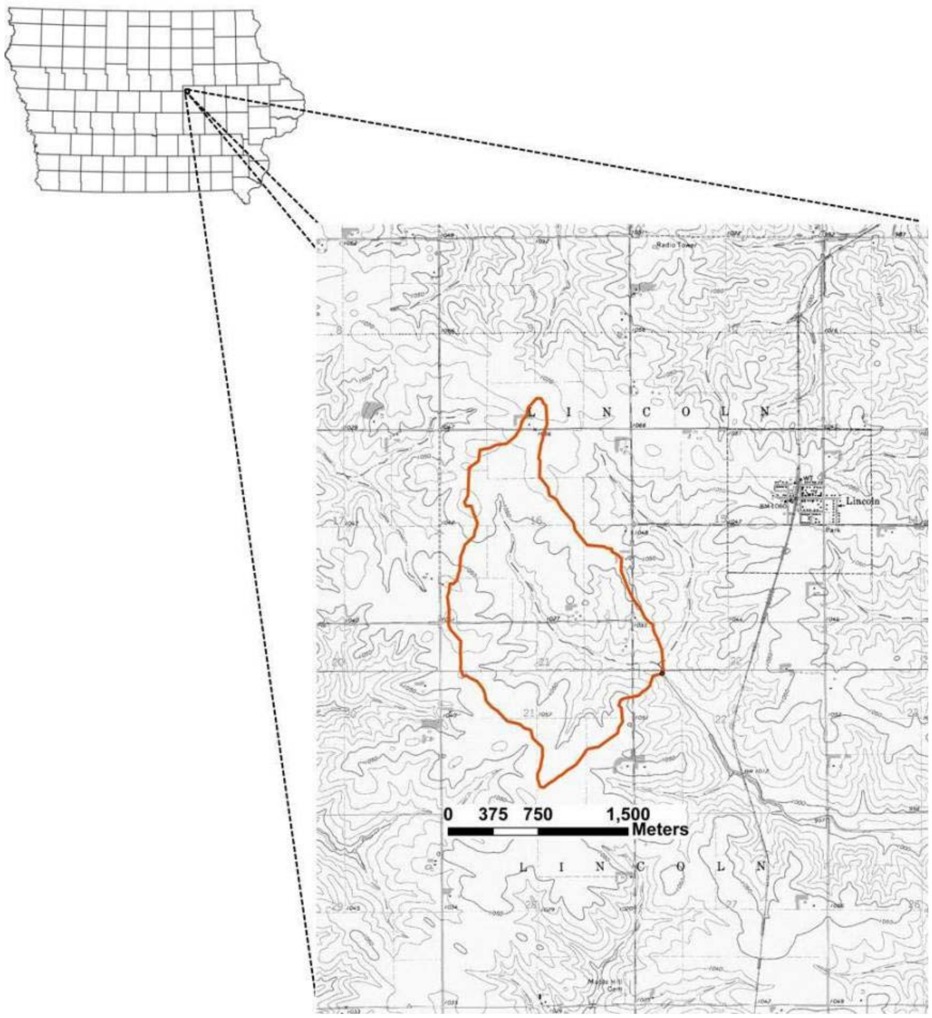

Figure 1 Example 296 ha watershed in Tama County, Iowa, used for model simulations.

Stakeholder perceptions were sought by asking three different focus groups questions about variability and uncertainty with reference to the above comparison of prediction methodologies. Participants in each of the three focus groups were invited based on their professional interests and perspective of soil erosion and sediment load delivery. The focus groups provided collective insights from different stakeholder types regarding the usefulness of improved uncertainty analysis and statistical techniques.

Stakeholder Focus Groups

Scientists have convincingly argued for improved NPS modeling and better statistical methods for quantifying prediction uncertainty (USEPA 2002), yet little evidence exists showing that these technical improvements result in better land management. Uncertainty is a vague concept, involves risk, and different people respond differently to risk. Stronger scientific evidence should result in better application. The focus group study of soil erosion and sediment delivery stakeholders is included as part of this work for additional perspective of erosion prediction science and real world outcomes.

The focus group study was organized and conducted following the guidance of Krueger and Casey (2009). Three stakeholder types define the makeup of each focus group. The focus group method requires homogeneity with respect to the topic under discussion. The participants may be diverse in other respects but must have a common interest in controlling soil losses from agricultural lands. When properly conducted, focus groups provide collective insights into perceptions of the community. Focus group results are different from individual interviews, which provide individual perspectives (Krueger and Casey 2009).

This focus group study was organized into three stakeholder types; science professional, environmental and producer. These three types have different relationships with the land and suffer different consequences from excessive soil erosion and sediment transport. All three groups have an interest in reducing soil erosion as much as possible, yet they have been known to disagree about actions to take to address the soil erosion problem. By questioning the three groups independently regarding soil erosion and sediment transport uncertainties, common and conflicting perceptions can be revealed. The science professional focus group consisted of five individuals charged with studying and improving surface water quality. A second focus group was attended by eleven individuals with “environmental interests” and a third group consisted of five individuals with “agricultural production interests”. Individuals in the technical professional group represented government and academic entities. The environmental interest group was represented by local, state and national environmental organization members. The participants of the production interest group were individual farmers and representatives of agricultural production organizations. All individuals that participated in each of the three focus group meetings were college educated and well informed regarding soil erosion and sedimentation processes.

Each of the three meetings was held at a neutral and convenient location for the participants. The discussion was recorded by audio tape and transcribed to written text for analysis. The moderator of the meeting posed questions to each group as the conversation proceeded. The following questions were prepared in advance and used as a guide for each meeting discussion:

1. How can we control soil erosion and sediment loss under agricultural land uses?
2. What is meant by “the 2 year precipitation event?” How does it differ from “the 2 year erosion event”?
3. What methods of erosion prediction are you familiar with? What do you use erosion models for? What are their strengths and weaknesses?
4. How important is it that prediction of future soil erosion be accurate (that what really happens matches what was predicted) when you install or recommend the best practices mentioned before?

5. How useful is it to know the probability that the soil erosion goal will be met?
6. (Display and explain Figure 3) What questions come to your mind as you compare these two? How much do the differences matter to you?
7. When you evaluate soil erosion and sedimentation what other kind of information would be useful to you?

The focus group meetings took place in the fall of 2009, with about one month between the meetings. The technical professionals met first followed by the environmental group. The production interests group met last in early December of 2009. A research team consisting of a PhD student, one associate professor of agricultural and biosystems engineering and one associate professor of sociology analyzed the focus group meeting transcripts independently. After the independent analyses, the research team members met to discuss and document key themes from each of the focus group discussions. A qualitative analysis of the focus group data and further discussion of implications follows in the Results and Discussion section.

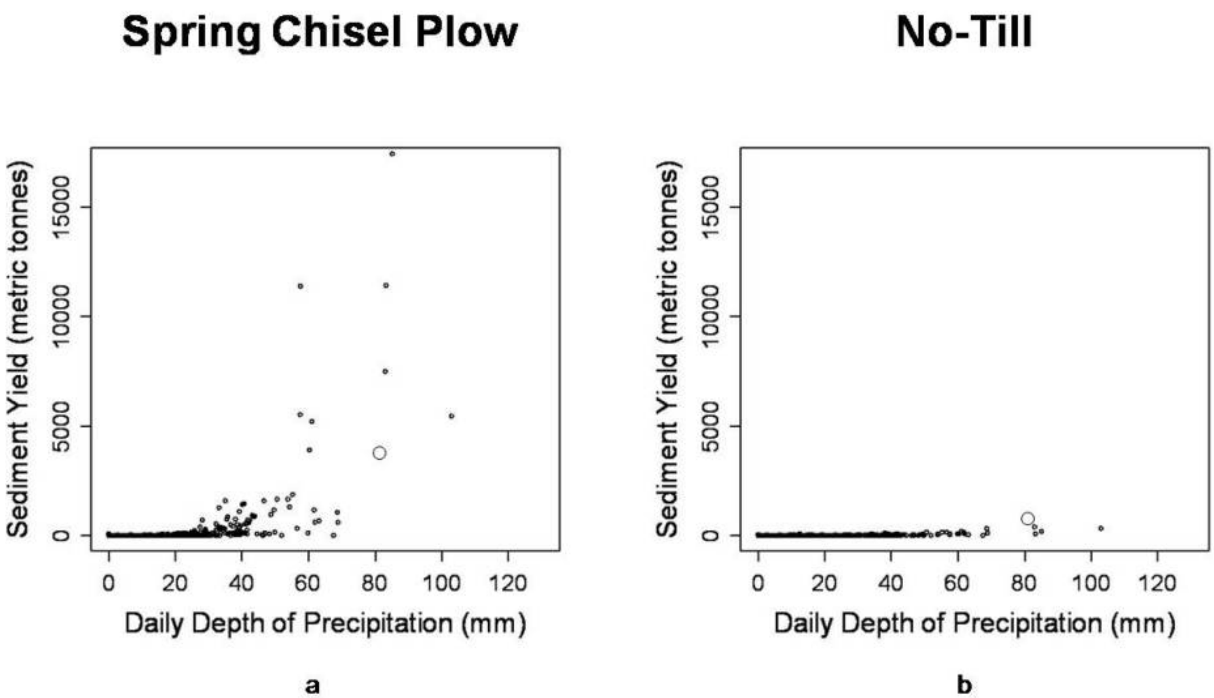

Figure 2 Comparison the deterministic output of MUSLE for the 2–year, 24–hour single event (open circles) and 20 years of stochasticoutput from WEPP (solid dots) for spring chisel plow and no–tillscenarios.

Results and Discussion

The sediment yield estimates from the GeoWEPP stochastic method and the MUSLE deterministic method are presented for the example watershed. Next the analysis of the focus group interviews is discussed. Because climatic factors, particularly rainfall depth, are the greatest source of uncertainty in sediment yield predictions (Nearing et al. 1990, Tiscareno-Lopez et al. 1993, Zhang and Yu 2004), we first present the results of sediment prediction with precipitation as the independent variable of interest (Figure 2).

WEPP Stochastic Method

The output from the Monte Carlo simulations of WEPP generated 5000 sets of 20 years of sediment yield for the example watershed. The data presented in Figure 2a is just one of the

5000 potential outcomes from the spring chisel scenario. It shows the sediment yield estimate for each precipitation event during one example 20–year period stochastically generated by CLIGEN. Because of the stochastic nature of each climate data set, each simulation yields different sediment delivery output.

Figure 2b shows the sediment yield estimate for the no–till scenario using the same climatic data set. In this simulation, no–till clearly reduces sediment delivery compared to the spring chisel plow scenario (Figure 2a). The data generated from each of 5000 simulations is used to construct a probability distribution as presented in Figures 4 and 5.

Criteria for developing a meaningful distribution must be consistent and depend on the target. As discussed before, the target has two components; the defined load and the acceptable frequency of exceeding the load. The two examples of uncertainty calculations presented are from the same climate data input and sediment yield output. Only the criteria for the target has changed.

MUSLE Deterministic Method

The MUSLE approach using a precipitation event frequency of 2 years and a 24 hour duration provides a single predicted value of sediment yield for the two management scenarios (Figures 2a and 2b). The MUSLE predictions are well within the range of sediment yield predictions fromWEPP. However, beyond the knowledge of the precipitation event probability, no other quantifiable measure of uncertainty can be inferred from the MUSLE solution. The timing of the storm event used in the MUSLE analysis can affect the predicted amount of sediment delivery significantly. For intensive tillage systems, the cover conditions that determine the C–factor in MUSLE vary greatly throughout the year. For example, the C–factor at May planting of continuous corn after moldboard plow and disk has been estimated to be 0.52. By mid July of the same year the C–factor for the same cropping system would be expected to decrease by more than half to a value of about 0.20. Cover conditions in no–till corn of a corn–soybean rotation follow a similarly trend, the C–factor decreasing from 0.17 in mid May to 0.08 in mid July (Laflen et al. 1985).

In the past, the IDNR has relied on MUSLE as a deterministic model for sediment TMDLs. However, the stochastic method using WEPP and CLIGEN provides more information for explicit uncertainty analysis as recommended by The Twenty Needs Report (USEPA 2002). The usefulness of one prediction method over the other may be perceived differently by different stakeholders. The focus group component of this study provides some insight into how different stakeholders in the community are influenced by the different types of uncertainty information.

Stakeholder Focus Group Perceptions

The questions posed to the stakeholder focus groups of this study were designed to guide each conversation toward the issue of sediment delivery prediction uncertainty, exceedance probabilities and a comparison between the stochastic and deterministic methods. The focus group discussion transcripts reveal important perceptions of each of the three groups which, if clearly understood, may be useful for improving the TMDL program and NPS pollution control in general.

The general consensus of each of the three focus groups was that more data provided by the stochastic approach helps to understand the highly variable nature of sediment delivery events and the difficulty of predicting sediment loads. Despite the variability of the output data, all three groups expressed that the stochastic comparisons between the two management scenarios provide a more convincing argument for the implementation of no–till rather than spring chisel

(Figure 2). One participant from the environmental interest group commented the following with regard to the prediction method comparison:

> "Having the extra data points makes a huge difference...I'd like to see another 57 conservation practices all analyzed this way with the stochastic method..."

Such enthusiasm for the stochastic approach, while welcomed by those of us dedicated to NPS modeling, were tempered by concerns of the science professionals group regarding excessive computations demanded by Monte Carlo simulations. The producer group was initially cautious in expressions of approval for quantified probabilities. However, after more discussion about the data, the producer group appreciated how the stochastic approach better explains the risk of failure, even with the best erosion control practices in place.
Interest in the statistical analysis and comparison of stochastic and deterministic methods was overshadowed by a stronger desire on the part of all three focus groups to express their concern, even frustration, with the persistent reality of soil erosion, sedimentation and other NPS pollution problems. For all three focus groups in this study, statistically computed quantified uncertainty of model predictions was of secondary importance. The primary issue discussed was technical complexity of NPS transport processes and social obstacles inhibiting significant changes needed for improving soil management and offsite effects.

Both science professional and producer groups spoke frequently of the complexity of researching, and the difficulty of controlling, soil erosion and other NPS pollutants. These two groups expressed frustration over the inability of the broader public, including policy-makers, to understand the dilemmas faced by technical professionals and producers. The science professional group referred to the recently published State-EPA Nutrient Innovations Task Group August 2009 report "An Urgent Call to Action" (USEPA 2009) as a good example of these misunderstandings. The report states that nutrient application does not match crop needs and a "proper rate and timing" for nutrient application can "reduce the amount of nutrients released from farm fields". While the report is factually correct, this is an over–simplification of a very difficult problem. It implies that clear technical solutions exist for reducing nutrient loads, much of which is carried by sediment. This is in direct contrast to views expressed by the technical professionals focus group:

> "The technical arenas are quite confusing. They are not clear at all, particularly when it comes to water quality and nonpoint source landscapes."

In the context of the same issue, the production group spoke similarly:

> "That's very important because a lot of times they just, you know, somebody says if they just do that, that will fix the problem and it's not anyway near that simple."

The environmental interest group spoke less of the difficulties brought on by the complexity of soil erosion control. The tone was more forgiving of the scientific shortcomings. The group was willing to accept and eager to deal with the realities of this complex problem:

> "...it doesn't matter that its accurate, ... it's a guide. It's not going to be the final product. For us it's more important the money is there to continue the refinement of the model."

The environmental focus group more often spoke of social factors such as peer pressure and guilt at the local coffee shop for gaining community support for natural resources stewardship.

Interestingly, the production group also spoke of using the farmer’s social network as an effective way to motivate less progressive land managers.

Just as engineers have often fail to consider the social aspects of technological applications, social scientists find it difficult to keep pace with the physical science disciplines. For example, the science professionals group spoke of the relatively advanced understanding and prediction capabilities for in–field movement of soil particles for sheet and rill erosion, but that our prediction capabilities fall short under conditions of classical gully erosion, streambank and perennial streambed erosion:

> “There are examples...where they maybe put thirty to forty percent of a ten thousand acre watershed into native prairie and we don’t see any change in sediment discharge from that watershed; where the models, the very simple models, would tell us we’d see a huge decrease in sediment from that watershed, but because we’ve not accounted for all the sources, particularly probably bed and bank sources,...we see no change after a ten year period”

Sediment load prediction for watersheds that approach the typical TMDL area of many square miles are weakened by assumptions of streambank and streambed contributions or by neglecting them entirely. This weakness in simulating in–stream processes may often be poorly understood by sociologists working on water quality issues. Technical shortcomings should be communicated better to those outside the technical arena.

> “...as technical people we could provide a clear message and clearer technologies and more understandable approaches and practices and what they will achieve.”

The focus group discussions suggest that the difficulties of effectively controlling NPS pollution, be it insoluble sediment particles, pollutants adsorbed to the sediment, or soluble pollutants, go well beyond the issue of statistical quantification. They suggest that NPS control strategies, as they exists today, fail to consider the very complex nature of NPS pollution. These complexities are still poorly understood and communicated. They include not only complexities of the physical system but also complexities of our social structure. Careful thought and caution on all sides are advised for the next generation of conservation policies:

> “It’s not so much the will to do it, ... it’s so difficult. How do you do things? And you have to be very careful not to go down the wrong path and do something that does no good, costs a lot, and builds ill will.”

Conclusions

The stochastic method allows an improved analysis of uncertainty compared to the deterministic approach of MUSLE. The WEPP stochastic approach better illustrates the degree of variability and level of uncertainty in sediment delivery estimates.

The focus group study suggests that communicating uncertainty may better help the general public understand the difficulties of controlling soil erosion and sedimentation. Rigorous statistical analyses using stochastic models can help stakeholders better understand uncertainty. However, the value of very specific and detailed statistical information must be balanced with the value of the resources required to generate it, and the ultimate influence it has on land stewardship and erosion control.

Complexity of the soil erosion process, rather than uncertainty quantification, was the primary concern for the technical professional and production focus groups. A concern that environmentalists lack an understanding of the complex problem was expressed by these two groups. The environmental interest group, however, expressed understanding of the complexities of soil erosion and sediment delivery, but encouraged a continued effort for step–by–step improvements.

More knowledge and better understanding of social attitudes and behaviors are key to maintaining sustainable food production systems that limit soil and nutrient losses to our waters. It is time for a new look at the National Research Council report on TMDL needs (USEPA 2002) with greater consideration of the social obstacles to TMDL program success.

Acknowledgements

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